

**Human Research Program
Human Health Countermeasures Element**

Evidence Report Summary

***Impaired Ability to Maintain Control of
Vehicles and Other Complex Systems***

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1. PRD Risk Title: Risk of Impaired Ability to Maintain Control of Vehicles and Other Complex Systems

Description (Updated since PRD release): Space flight alters sensory-motor function, as demonstrated by documented changes in balance, locomotion, gaze control, dynamic visual acuity, eye-hand coordination, and perception. These alterations in sensory-motor function affect fundamental skills required for piloting and landing airplanes and space vehicles, driving automobiles and rovers, and operating remote manipulators and other complex systems. However, relationships between the physiological changes and real-time operational performance decrements have not yet been established, owing to both the inaccessibility of operational performance data and the presence of confounding, non-physiological factors in most known instances of significant operational performance decrement. While space-flight induced alterations in sensory-motor performance are of concern for upcoming lunar missions, they are of greater concern for Mars missions due to the prolonged microgravity exposure during transit, which will more profoundly affect landing task performance and subsequent operation of complex surface systems.

II. Executive Summary of Evidence for Risk

Piloting spacecraft, especially through landings and rendezvous, and operating complex systems, such as robot arms and surface rovers, requires acute sensory-motor and cognitive skills as well as intensive training. A large body of extant experimental evidence demonstrates that the G transitions associated with spaceflight alter sensory-motor function, likely through adaptive mechanisms in the central nervous system (CNS) responding to loss (or return) of gravity-mediated stimulation of various sensory receptors. Changes observed in visual acuity, eye-hand coordination, and spatial orientation perception show significant performance decrements at (or soon after) G transitions that diminish with time thereafter. These spaceflight-related changes affect different crewmembers to different degrees, but for all crewmembers they become more profound and take longer to resolve as mission duration increases. There is also evidence suggesting that cognitive function is affected by spaceflight either through direct microgravity effects or through non-specific stress effects. It is likely that these changes affect crew performance of complex manual control tasks, particularly those required during dynamic (accelerating) phases of a mission. Whether these effects are operationally significant remains unknown, as the available evidence is so far largely indirect. Nevertheless, review of the Apollo landing and rover operations experiences suggest that the possible operational impacts of alterations in sensory-motor performance should be of concern for lunar missions. Furthermore, these alterations should become a greater concern for Mars missions due to the prolonged microgravity exposure during transit. The true operational risks will only be estimable when we can accurately assess integrated performance in off-nominal operational settings. Exclusive crew selection procedures, intensive crew training, and highly reliable hardware/software systems have likely minimized the operational impacts of these sensory-motor changes to date, but the impacts of new mission characteristics (especially duration) and vehicle designs may offset some of these benefits.

III. Risk in Context of Exploration Mission Operational Scenarios

1. Piloted Landings

Piloting a space craft through entry and landing is one of the most difficult tasks associated with spaceflight. The consequences of failing to complete this task successfully could be catastrophic, resulting in loss of life, vehicle, or other assets. While all piloted landings from space have been successful to date, the landing performance has been lower than desired for both the Shuttle and the Lunar Lander. To the extent physiological adaptations play a role in these performance decrements, we can anticipate that the risk of failure will become much greater during Mars missions. There is strong evidence that the six-month outbound trip will cause a much more profound sensory-motor adaptation to zero-g than occurs during a 1-2 week Shuttle mission. This will likely lead to a much more profound physiological response to the g-transition during entry/landing, although the impact of the reduced amplitude (3/8 G vs. 1 G) of the transition is unknown. Furthermore, piloting recency will decrease from 1-2 weeks during the Shuttle program to six months during a Mars mission, decreasing the probability that a pilot will be able to fly through any spatial disorientation that accompanies the g-transition. Even piloted landings on the Moon present some unique risks, despite the relatively short zero gravity transit phase, owing to the effects of the novel gravitational environment on spatial and geographic orientation and the potential for lunar dust obscuring vision during critical phases of landing.

2. Rover Operations

The risk of performance failure while driving an automobile (loss of vehicle control; having an accident) is high for vestibular deficient patients and for those whose cognitive and/or sensory-motor functions are impaired by ethanol, fatigue, or certain medications. Crewmembers readapting to Earth-gravity following return from spaceflight exhibit similar performance decrements, and, as a result, are currently restricted from driving automobiles for a short time (2-4 days) after Shuttle missions and a longer time (8-12 days) after ISS missions. The impact of sensory-motor adaptations on driving rovers on either Moon or Mars is unknown. While the potential consequences of performance failure while driving a rover are less than those of piloting a space craft through entry and landing, the possibility of crew injury (or death) or loss of the rover exists, particularly in the vicinity of steep-sided craters. The duration of the initial adaptation period to the Lunar or Martian gravity environment is also unknown, and, while likely to be proportional to the time spent in zero gravity transit, cannot be determined until it can be measured on the planetary surface. Thus, the amplitude and duration of increased risk during rover driving are currently unknown.

3. Rendezvous/Docking and Remote Manipulator System Operations

Performance data on rendezvous/docking has so far eluded the authors. However, the incidence of performance failure during remote manipulator operations aboard the Shuttle and ISS has been fairly well characterized (at least operationally). There is no reason to suspect that performance of these zero-g operations will be any different from our ISS experience during an outbound transit to Mars. Thus, we would not expect the risk to increase. However, the risk impacts of an additional 18 months at Mars gravity followed by six months at zero-g during return transit are unknown, and may well lead to an unacceptable range.

4. Other Complex Systems

The risk of performance failure during operation of any complex system is multi-factorial. However, operation of any system requiring good visual acuity, eye-hand coordination, (balance/locomotor skills for surface operations), spatial orientation, and/or cognition could be impaired by physiological adaptations to novel gravitational environments. The risk of impairment is generally greatest during and soon after G transitions, but the amplitude and duration of the increased risk would need to be evaluated on a system-by-system basis.

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